The U.S. GOVERNMENT

IS ABSOLVED

FROM ANY LITIGATION WHICH MAY

ENSUE FROM THE CONTRACTORS IN-

FRINGING ON THE FOREIGN PATENT

RIGHTS WHICH MAY BE INVOLVED.

WRIGHT FIELD, DAYTON, OHIO

UNCLASSIFIED

Wake Survey of the Mark 13 Torpedo

26639

(None)

Eggers, H. A.
David Taylor Model Basin, Washington, D. C.
(Same)

R-583

July '47 Unclass. U.S. Eng. 10 photos, diagrs, graphs

The distribution of velocity and pressure astern of a full-scale Mark 13 torpedo with and without a shroud ring was determined at a speed of 7 knots. The results of the tests indicate that, the shroud ring has little effect on the wake over the inner part of the propeller disk area, but increases the wake 1 to 2% in the outer part of the area. The difference between the local static pressure when the torpedo is underway, and the hydrostatic pressure when the torpedo is at rest is a maximum at the center of the after end of the propeller nut, and approaches zero 36 inches aft of the after end of the propeller nut. The increase of static pressure throughout the wake area represents a relatively small part of the total stream energy astern of the torpedo.

Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

Ordnance and Armament (22)
Torpedoes and Mines (9)

(94537)

Torpedoes, Naval - Hydrodynamics

R-22-9

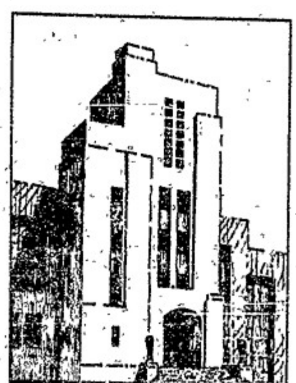
ATI No. 26639

THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

WAKE SURVEY OF THE MARK 13 TORPEDO

BY H. A. EGGERS



JULY 1947

REPORT 583

REPORT 583

WAKE SURVEY OF THE MARK 13 TORPEDO

BY H. A. EGGERS

JULY 1947

WAKE SURVEY OF THE MARK 13 TORPEDO

ABSTRACT

The distribution of velocity and pressure astern of a full-scale Mark 13 torpedo with and without a shroud ring was determined at a speed of 7 knots. The results of the tests indicate that the shroud ring has little effect on the wake over the inner part of the propeller disk area but increases the wake 1 to 2 per cent in the outer part of the area. The difference between the local static pressure when the torpedo is underway and the hydrostatic pressure at rest is a maximum at the center of the after end of the propeller nut and approaches zero 36 inches aft of the after end of the propeller nut. The increase of static pressure throughout the wake area represents a relatively small part of the total stream energy astern of the torpedo.

INTRODUCTION

When a torpedo passes through water, it imparts motion to the neighboring fluid particles. The aggregate motion of these particles relative to undisturbed water is known as the wake. The wake of a torpedo is nearly symmetrical about the axis of the torpedo but varies otherwise from point to point in both magnitude and direction. The circumferential average of the wake at every radius, measured in the propeller plane, is an important factor for consideration in determining the pitch distribution and other design features of propellers.

In accordance with a request of the Bureau of Ordnance (1),* the David Taylor Model Basin undertook the exploration of the wake astern of a full-size Mark 13 torpedo without a shroud ring. The program was later broadened to include the distribution of wake and pressure when the torpedo was fitted with a shroud ring (2)(3).

TEST SETUP AND PROCEDURE

The tests to determine the velocity distribution astern of a Mark 13 torpedo without a shroud ring were conducted by means of a 6-element pitot rake. As shown in Figure 1, the pitot rake consists of 6 small pitot tubes mounted on the leading edge of a streamlined strut. The survey of the distribution of the pressure and the velocity astern of the torpedo fitted with a shroud ring was conducted by means of a 13-hole spherical pitot tube, shown in Figure 2, and in Figures 12 and 13 on pages 17 and 18.

* Numbers in parentheses indicate references on page 15 of this report.

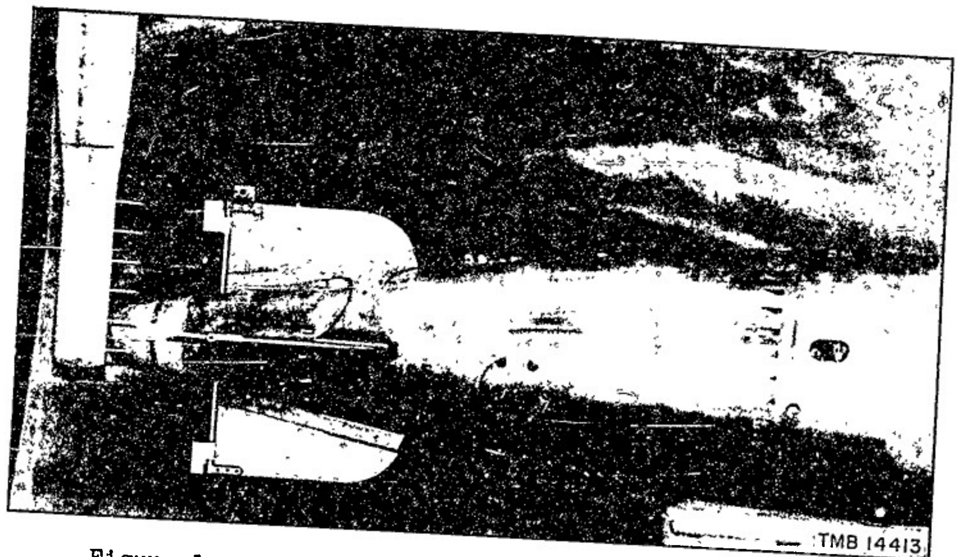


Figure 1 - Arrangement for Measuring the Wake of the Mark 13 Torpedo with a 6-Hole Pitot Rake

The propellers were replaced by dummy hubs. The view shows the pitot rake with the piezometer openings placed 3 inches forward of the after end of the propeller nut.

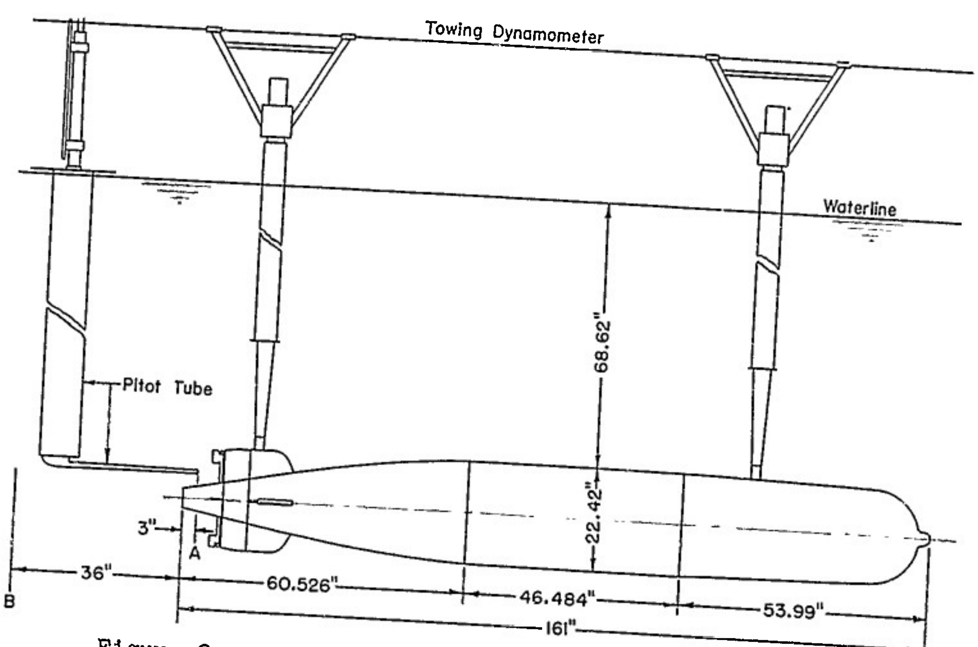


Figure 2 - Towing Arrangement for the Wake Survey of the Mark 13 Torpedo with Shroud Ring

The sketch shows the mounting of the torpedo and the pitot tube for measuring the wake at A, the mid-plane of the propellers, with the 13-hole spherical pitot tube. A survey was also made at B, a plane 36 inches aft of the after end of the propeller nut. A preliminary survey was made along the torpedo axis at 6-inch intervals from 6 inches to 42 inches aft of the after end of the propeller nut.

OPERATION WITH THE PITOT RAKE

The torpedo without a shroud ring, but with the propellers replaced by dummy hubs, was suspended from the floating girder of Carriage 2 over the deep-water basin at a submergence of 68.62 inches to the top of the torpedo, similarly to the arrangement in Figure 2. Since the wake of the torpedo is assumed to be symmetrical about the torpedo axis, only one quadrant was explored. The velocity of the water parallel to the axis at the midplane of the propeller hubs was obtained by measuring the axial components of the velocity heads at various points.

In the tests the pitot rake was hung vertically from the girder with the dynamic pressure openings in the midplane between the two propeller hubs, as shown in Figure 1. The dynamic and static pressures were measured by a 12-tube water manometer connected directly to the pitot tubes by copper and rubber tubing. Prior to the runs, the datum pressure level was raised from the level of the water in the basin to a convenient height on the manometer by reducing the pressure in the manifold connecting the tops of the tubes. The arrangement of the manometer and associated apparatus is shown in Figure 3.

The dynamic and static pressures at the pitot-tube positions were measured at a torpedo speed of 7 knots. Generally, the levels of the water in the manometer tubes reached a steady height during one run. However, if the heights of the water columns were unsettled at the end of the run, the petcocks were closed before the carriage started to decelerate, and were opened again on the next run after the carriage speed became constant. The runs were repeated until the levels in the manometer tubes remained constant. After the heights of the water columns in the manometer tubes were recorded, the pitot rake was placed in another position and the operation was repeated until the entire quadrant had been explored.

OPERATION WITH THE 13-HOLE SPHERICAL PITOT TUBE

The torpedo equipped with a shroud ring, but with the propellers replaced by dummy hubs, was suspended from the floating girder of Carriage 2 over the deep-water basin at a submergence of 68.62 inches to the top of the torpedo, as shown in Figure 2. The three locations explored were:

1. The upper port and lower starboard quadrants in the midplane between the two propeller hubs, as shown in Figure 7 on page 9.

2. A segment of the torpedo axis astern of the torpedo at 6-inch intervals, from 6 inches to 42 inches aft of the after end of the propeller hub, as shown in Figure 6 on page 8.

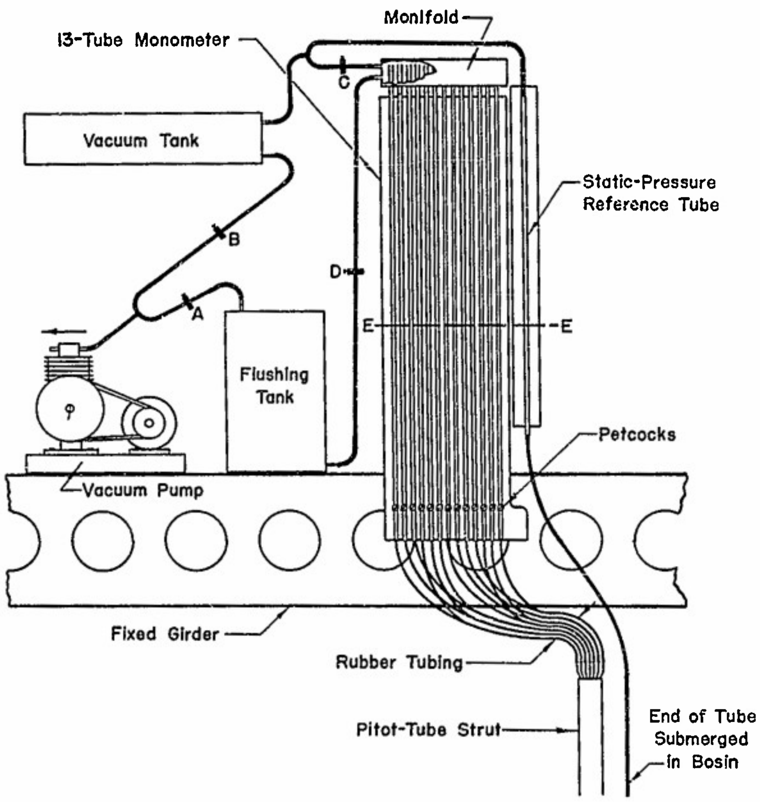


Figure 3 - Diagrammatic Arrangement of the Manometer and Pitot-Tube Connections

Each tube of the manometer is connected to one of the 13 holes of the pitot tube. The system is then filled by opening the pinch clamps A and D and evacuating the flushing tank, thus drawing the water of the basin into the tubes and allowing it to spill over into the tank. The flushing is continued until all the tubes and leads are cleared of air bubbles. The pinch clamps A and D are then closed and B is opened. The pressure in the vacuum tank is reduced until the water column in the static reference tube reaches a convenient height E-E. The pinch clamp B is closed and C is opened to allow the water columns to settle to E-E. Pinch clamp D is then momentarily opened until the manifold is entirely drained of water. The manometer-tube water levels obtained from a run are maintained by closing the petcocks before the carriage starts to decelerate at the end of each run. They are opened again on the next run after the carriage speed becomes constant.

3. The lower starboard quadrant and the two 45-degree diagonals in a plane 36 inches aft of the after end of the propeller nut, as shown in Figure 9 on page 11.

The selected points of exploration for Locations 1 and 3 were arranged at 2-inch horizontal and vertical intervals. The maximum velocity, the direction of flow, and the difference in pressure with the torpedo at rest and at a speed of 7 knots were obtained at these points, using the 13-hole spherical pitot tube for the measurement of the velocity and pressure at each point. The method of operation of this tube is described in the Appendix.

TEST RESULTS

The test results are shown in Figures 4 through 10. Figures 4 and 5 represent the wake distribution obtained with the pitot rake in the midplane between the propellers of the Mark 13 torpedo without a shroud ring. The velocity of flow at each position of the pitot tubes was obtained by using the dynamic pressure formula

$$V_a = \sqrt{2gh} \qquad [1]$$

where V_a is the velocity in feet per second of the longitudinal flow relative to the torpedo at the position of the pitot tube,

H is the difference in feet between the height of the water in the impact tube and the height in the static tube as measured on the manometer, and

g is the acceleration of gravity in feet per second per second.

The wake fraction at each position was then calculated by the use of Taylor's notation (5)(6)

$$w = \frac{V - V_a}{V} \times 100 \qquad [2]$$

where w is the wake fraction in per cent and V is the speed of the torpedo relative to undisturbed water in feet per second.

The values obtained from Equation [2] were plotted and cross-faired horizontally and vertically to obtain the contours of equal wake shown in Figure 4. The values of the circumferential mean wake w_r for the curve labeled "Average Wake at any Radius," Figure 5, were obtained by evaluating the expression,

$$w_r = \frac{\int_0^{2\pi} w\,d\theta}{\int_0^{2\pi} d\theta}$$

at constant radii; thus w_r is the integral average of the wake taken around a circle of a fixed radius r, and w denotes the value of the wake at any point on the circumference. The expression $\int_{r_1}^{r_2} 2\pi r\, w_r\, dr / \int_{r_1}^{r_2} 2\pi r\, dr$ was then integrated and plotted as a function of r to obtain the curve labeled "Area Mean Wake in the Midplane between the Propeller Hubs," Figure 5.

The test results obtained with the 13-hole spherical pitot tube are shown on Figures 6, 7, 8, 9, and 10. The wake diagrams are self-explanatory.

(Text continued on page 13)

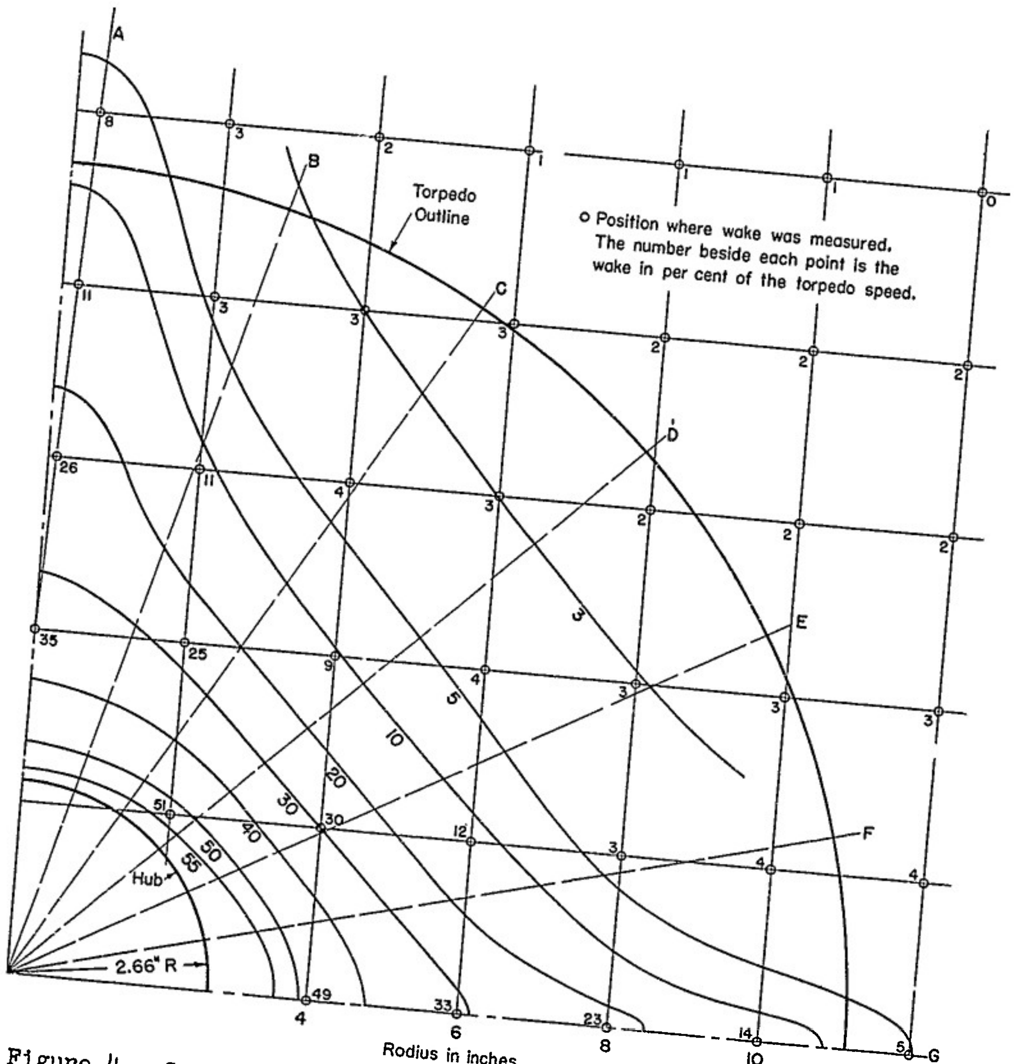


Figure 4 - Contours of Constant Wake in the Midplane between the Propeller Hubs of the Mark 13 Torpedo without a Shroud Ring

These contours were obtained by cross-fairing, along vertical and horizontal lines, the wake values measured with the 6-hole pitot rake. The torpedo speed was 7 knots.

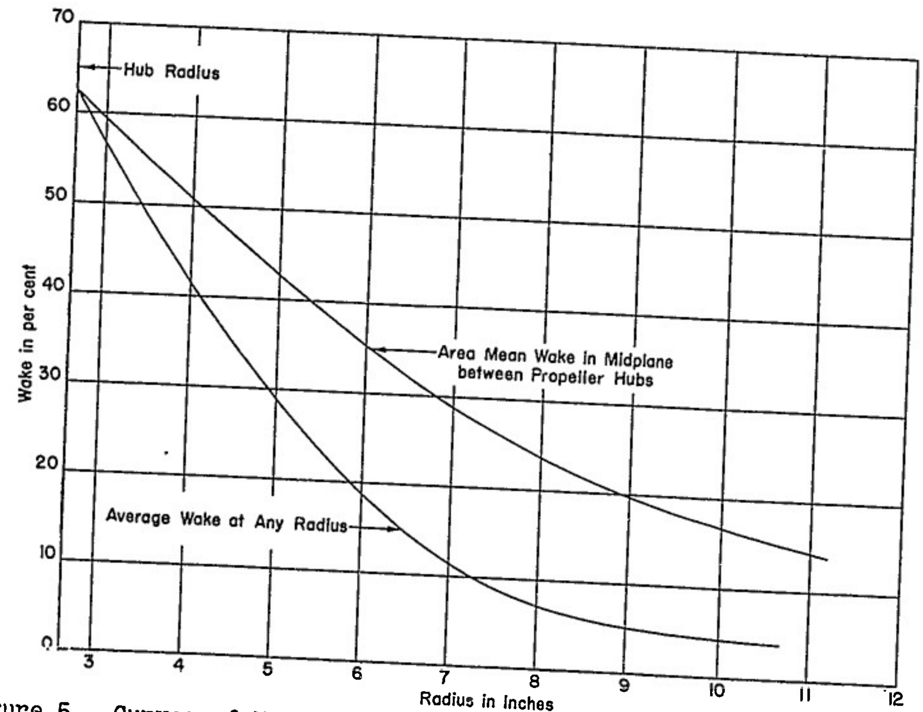


Figure 5 - Curves of Wake of the Mark 13 Torpedo without a Shroud Ring

The wake was measured 3 inches forward of the after end of the propeller nut.

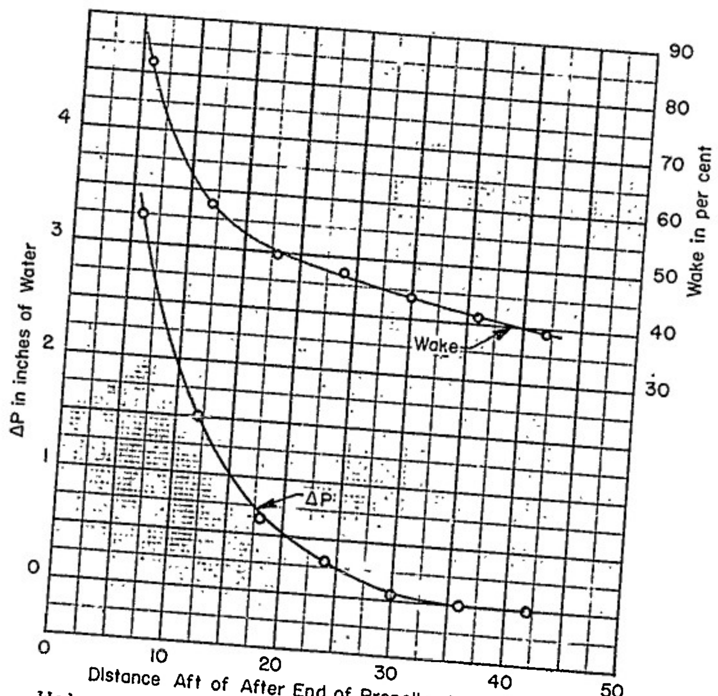
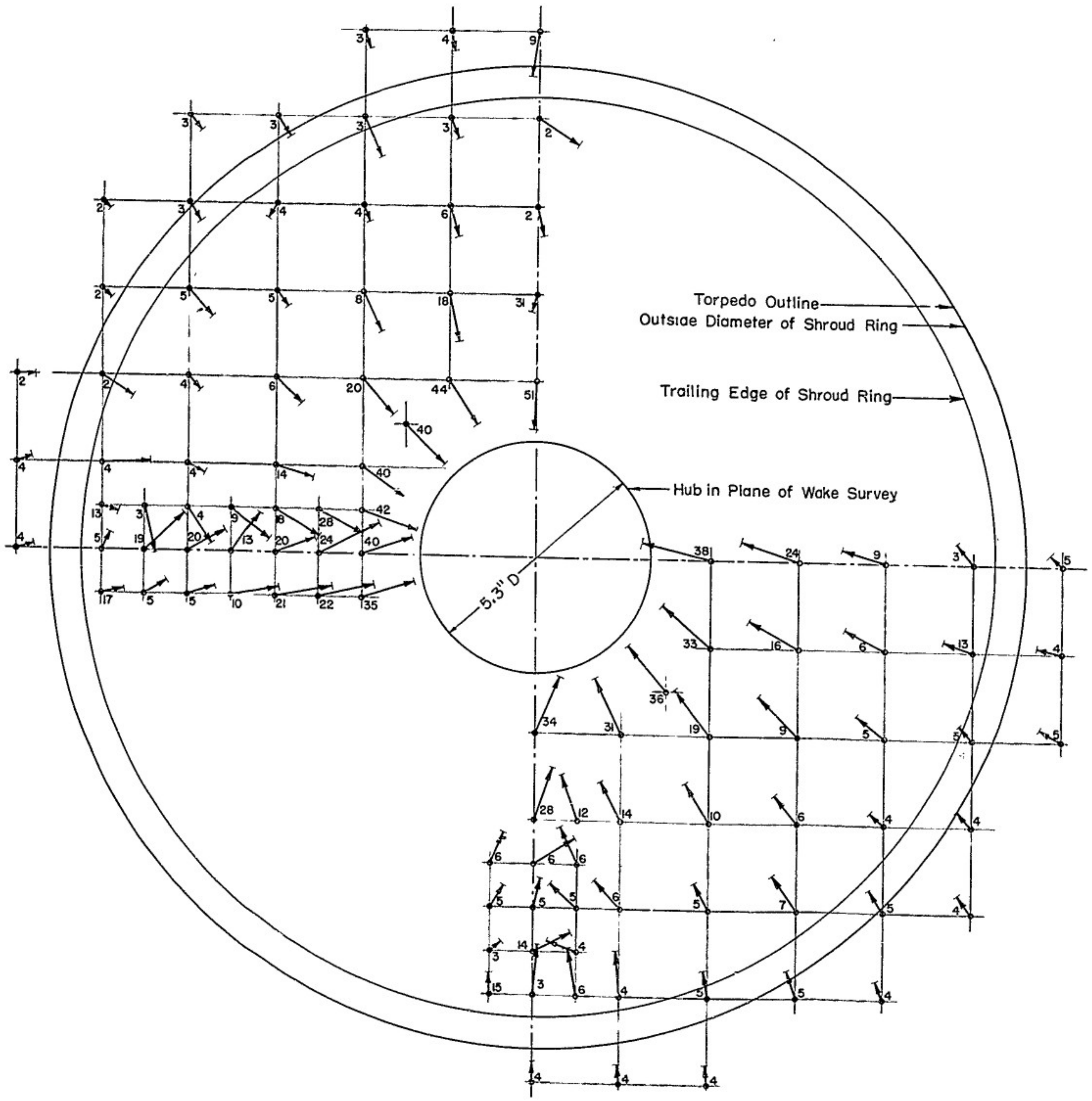


Figure 6 - Wake and Local Static-Pressure Change Measured Along the Axis of the Mark 13 Torpedo with Shroud Ring

ΔP is the change of the local static pressure, from rest to a speed of 7 knots, along the axis aft of the torpedo.

Wake is $1 - \frac{\text{Speed of Water}}{\text{Speed of Torpedo}}$.



Y-Z Plane, Looking forward

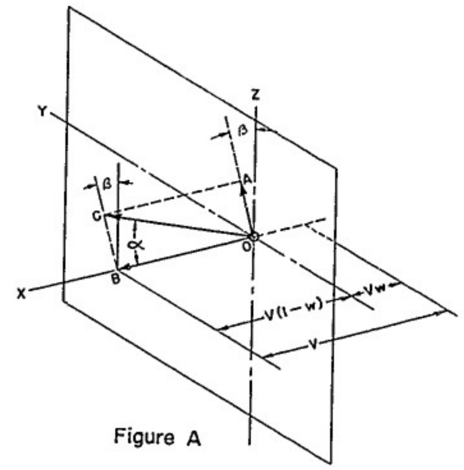


Figure A

The Y-Z plane in Figure (A) represents a section through the torpedo at the point of measurement.

Vector $\overline{OA}$ lies in the Y-Z plane and is shown in the flow diagram. This vector indicates the transverse flow components in magnitude and direction.

Vector $\overline{OB}$ is parallel to the centerline of the torpedo. Its length is equal to the torpedo speed multiplied by (1 – w), where w is the wake fraction.

Vector $\overline{OC}$ is the resultant velocity of flow relative to the torpedo.

The relationships between the vectors $\overline{OA}$, $\overline{OB}$, and $\overline{OC}$ are shown in Figure (B).

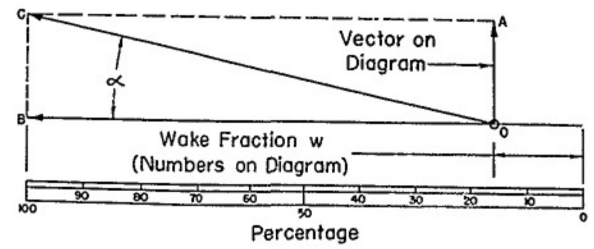


Figure B

Figure 7 - Wake in the Midplane between the Propeller Hubs of the Mark 13 Torpedo with Shroud Ring

The submergence to the top of the body was 68.62 inches.

The wake was measured in a plane 3 inches forward of the extreme after end of the propeller nut.

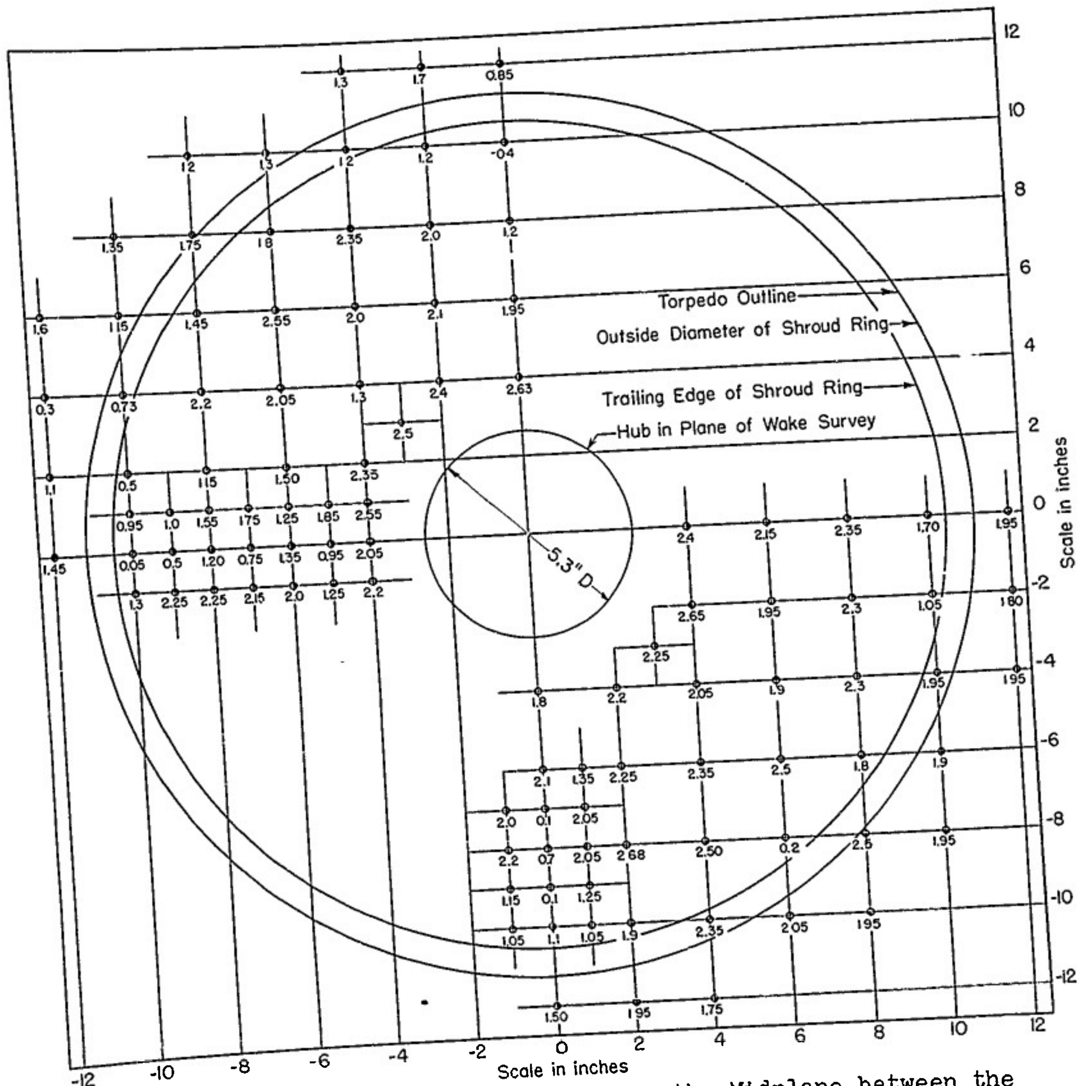
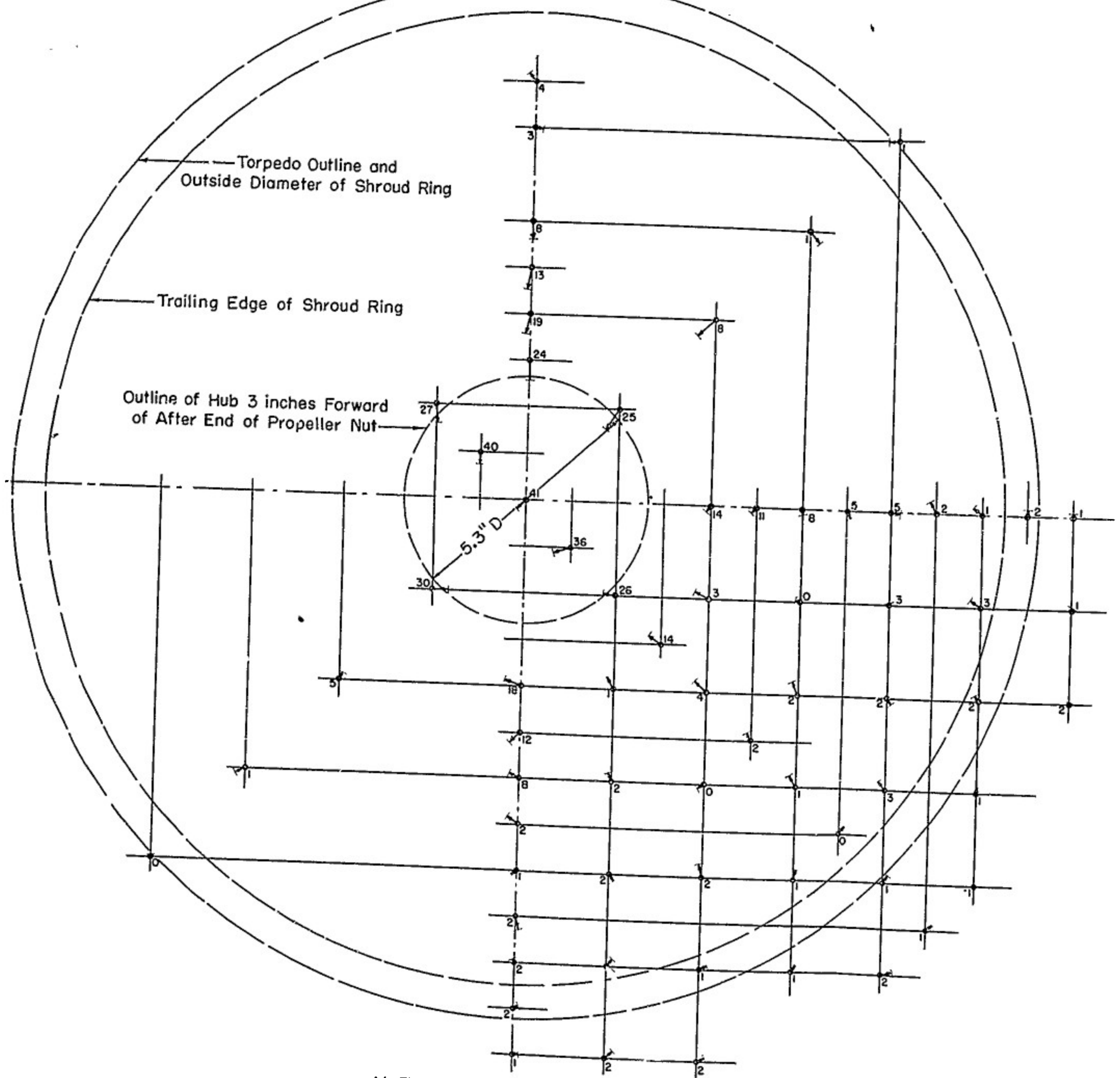


Figure 8 - Static-Pressure Change in the Midplane between the Propeller Hubs of the Mark 13 Torpedo with Shroud Ring

The static pressure was measured in a plane 3 inches forward of the extreme after end of the propeller nut. Static-pressure change is the difference in inches of water between the static pressure at a speed of 7.0 knots and the static pressure at rest.



Y-Z Plane, Looking Forward

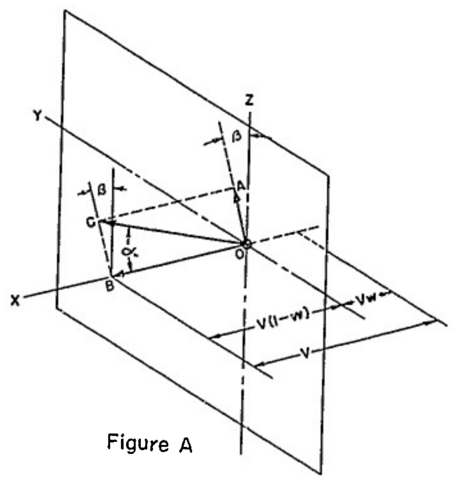


Figure A

The Y-Z plane in Figure (A) represents a section through the torpedo at the point of measurement.

Vector $\overline{OA}$ lies in the Y-Z plane and is shown in the flow diagram. This vector indicates the transverse flow components in magnitude and direction.

Vector $\overline{OB}$ is parallel to the centerline of the torpedo. Its length is equal to the torpedo speed multiplied by (1 - w), where w is the wake fraction.

Vector $\overline{OC}$ is the resultant velocity of flow relative to the torpedo.

The relationships between the vectors $\overline{OA}$, $\overline{OB}$, and $\overline{OC}$ are shown in Figure (B).

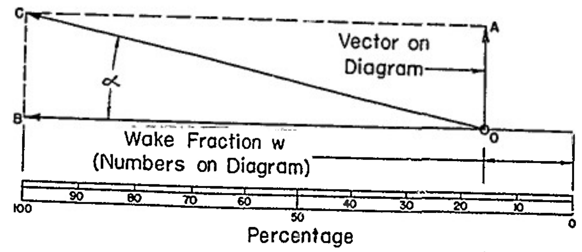


Figure B

Figure 9 - Wake 36 Inches Aft of the After End of the Propeller Nut of the Mark 13 Torpedo with Shroud Ring

The submergence to the top of the body was 68.62 inches.

The wake was measured in a plane 36 inches aft of the extreme after end of the propeller nut.

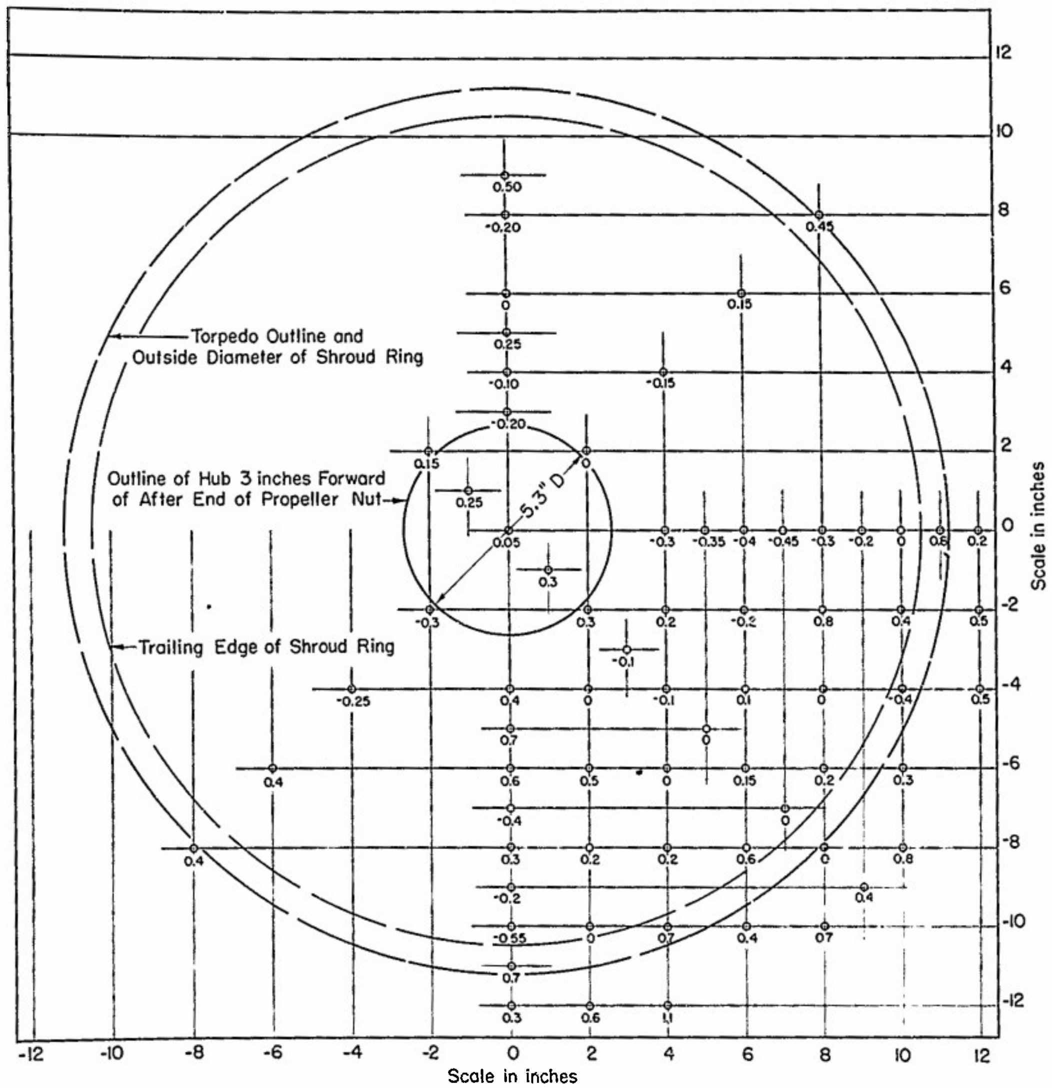


Figure 10 - Static-Pressure Change 36 Inches Aft of the After End of the Propeller Nut of the Mark 13 Torpedo with Shroud Ring

The static pressure was measured in a plane 36 inches aft of the extreme after end of the propeller nut. The static-pressure change is the difference in inches of water between the static pressure at a speed of 7.0 knots and the static pressure at rest.

DISCUSSION OF THE RESULTS

The complete analysis of the results of the survey and the effect of the velocity and pressure distribution astern of the torpedo on the propeller performance are beyond the scope of this report. Therefore, only the results of the tests and the relative accuracy of the data shown on the diagrams will be discussed.

A comparison of the wake survey made with the torpedo fitted with a shroud ring, using the spherical pitot tube, and the survey with no shroud ring on the torpedo, using the pitot rake, is shown on the composite diagram, Figure 11. Here the contours of equal wake obtained from the measurements with the 6-tube pitot rake, Figure 4, are superimposed on the wake values taken at the midplane between the propeller hubs with the 13-hole spherical pitot tube in the upper port quadrant, Figure 7.

Because of the uncertainty of the pressure field of the strut of the 6-tube pitot rake when operating in nonuniform flow and also the variation of the static pressure between the fore-and-aft location of the impact and the static openings of the pitot tubes, the values of wake obtained using this rake, Figure 4, are not considered as accurate as the values of wake obtained with the 13-hole spherical pitot tube. Therefore the numerical results shown at the various spots, Figures 7, 9, and 11, are considered to be the best indication of the local wake. In most instances where variances were appreciable, the spots were repeated in order to verify the values shown. The circumferential average mean wake at any radius obtained by either survey method is, however, approximately the same.

The results of the local wake and pressure tests taken in the midplane between the propeller hubs along the lower 45-degree diagonal are tabulated in Table 1, together with the results of the survey made at a similar position on a 1/6-scale model in the Harvard Wind Tunnel (4). The pressure coefficients are of the same order of magnitude near the hub, but as the shroud ring is approached the pressure coefficients determined at the Taylor Model Basin were found to increase, whereas those obtained by the Harvard Wind Tunnel decreased. The TMB velocity coefficients are somewhat higher near the hub than the Harvard results, both approaching unity just outside the shroud ring.

The numerical values of the static-pressure change are shown on the diagrams, Figures 8 and 9. They are the results of finding the difference between the local static pressure with the torpedo underway, as determined from the curves,* and the datum pressure on the manometer board established

---

* This method is described in the Appendix.

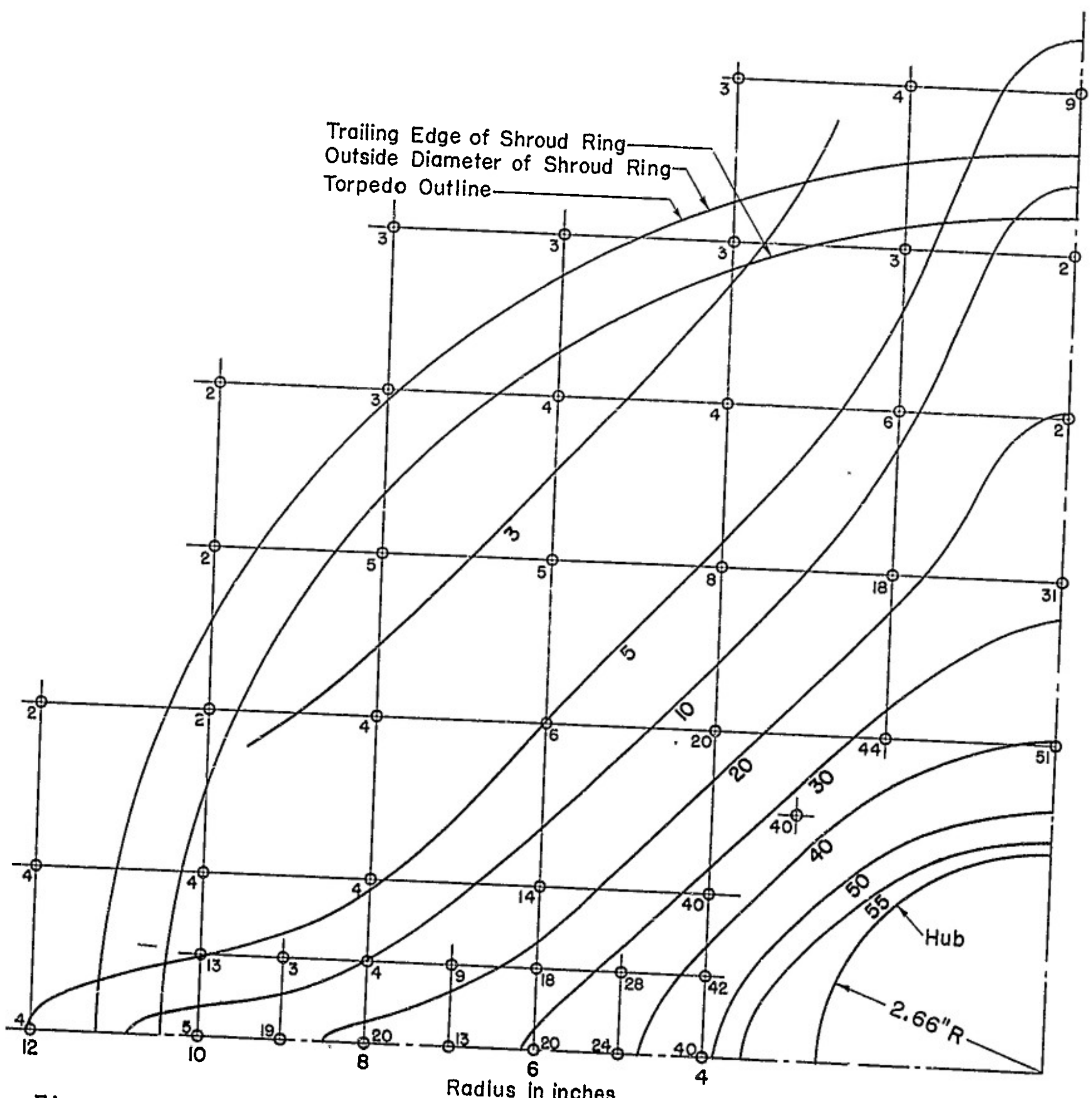


Figure 11 - Composite Diagram of the Results of the Wake Survey in the Midplane between the Propeller Hubs of the Mark 13 Torpedo with and without a Shroud Ring

The contours of equal wake are the rssulte of the wake survey of ths torpedo without a ehroud ring, made with a epherical pitot tube, as shown in Figure 4. The numbers placed beside the circlee are ths wake values of the torpsdo fitted with a shroud ring and measured with the 6-tube pitot rake, as ehown in Figure 7. All the wake values are expreesed in per cent of ths torpedo epeed.

TABLE 1

Wake and Pressure Coefficients of the Mark 13 Torpedo Fitted with a Shroud Ring

Distance from Torpedo Axis in per cent of Radius R of Torpedo Body	$C_p = \frac{\Delta P}{V^2/2g}$		$C_v = \frac{(1-w)V}{V}$	
	Harvard Wind Tunnel Measurements	TMB Measurements	Harvard Wind Tunnel Measurements	TMB Measurements
38	0.090	0.086	0.56	0.64
51	0.086	0.079	0.75	0.81
76	0.078	0.096	0.94	0.94
101	0.056	0.096	0.97	0.95

before making the run. It is impracticable to fair the curves of pressure distribution on the spherical pitot tube any closer than the nearest 0.10 inch of water. Therefore, although the static-pressure change shown on the diagrams is given to 0.05 inch of water, the actual static pressure indicated is accurate only to the nearest 0.10 inch of water.

The wake near the hubs in the midplane between the propeller hubs, Figure 11, is approximately 55 per cent of the speed of the torpedo. The wake on the torpedo axis 36 inches aft of the after end of the propeller nut, where the local static pressure becomes equal to the hydrostatic pressure, is 41 per cent, as shown in Figure 6. Therefore, the magnitude of the wake is only slightly diminished in the range in which the local static pressure returns to the hydrostatic pressure of the stream. Since there is no further conversion of velocity to pressure, the fluid velocities along the torpedo axis at this point must be representative of the frictional component of the wake. It is evident, therefore, that the frictional component of the wake predominates in the plane of the propellers near the hub. Under this condition it is shown in References (5) and (6) that a relatively low thrust deduction can be expected and a considerable amount of energy in the wake can be recovered by the propeller.

REFERENCES

(1) BuOrd CONFIDENTIAL letter NP21 (Re6a) of 27 September 1943 to TMB.

(2) BuOrd CONFIDENTIAL letter NP21 (Re6a) of 3 May 1945 to TMB.

(3) ORL RESTRICTED letter of 23 April 1946 to TMB.

(4) "The Wake of a Model of MK 13 Torpedo," ORL Report NOrd 7958-13, 30 March 1946.

(5) "Interaction between Propeller and Hull," by K.E. Schoenherr and A.Q. Aquino, EMB Report 470, March 1940.

(6) "Principles of Naval Architecture," by Rossell and Chapman, Volume II, p. 143.

APPENDIX

OPERATION OF THE 13-HOLE SPHERICAL PITOT TUBE*

When the pitot tube, Figures 12 and 13, is mounted in the position at which the wake is desired, the datum pressure level is raised from the level of the water in the basin to a convenient height in the 13-tube manometer by reducing the pressure in the manifold connecting the tops of the tubes, Figure 3. The torpedo is then towed at a constant speed. Each run is repreated if the change in the height of any water column from the previous run is more than 0.10 inch.

The manometer readings are plotted and two curves are drawn. One for the readings along the horizontal row of holes, called the port and starboard curves, and the other, in reversed orientation, for the readings along the vertical row of holes, called the top and bottom curves. A typical plot is shown in Figure 14. From these plots the location of the stagnation point and the angular direction to the pitot-tube axis of the horizontal and vertical components of the flow are determined, as shown in Figures 14 and 15.

The angular distance θ of the stagnation point from the pole, as measured on a great circle through the pole and the stagnation point of the flow, Figure 15, is found by the equation

$$\theta = \text{arc tan}\sqrt{(\tan h)^2 + (\tan v)^2} \qquad [3]$$

The velocity V_0 of flow at the location of the stagnation point on the sphere is obtained by dividing the velocity head at the pole by a correction coefficient obtained from the calibration curve, Figure 16, or

$$V_0 = \sqrt{\frac{2gH_p}{K_\theta}} \qquad [4]$$

(Text continued on page 22)

* This description will apply only to the use of the 13-hole spherical pitot tube for exploring the region astern of a torpedo. TMB Report 487 entitled "Instruments Used to Measure the Flow of Water Around Ships and Ship Models," by C.E. Janes, is in preparation. This report will describe in greater detail and give the more general uses of the spherical-ended pitot tube.

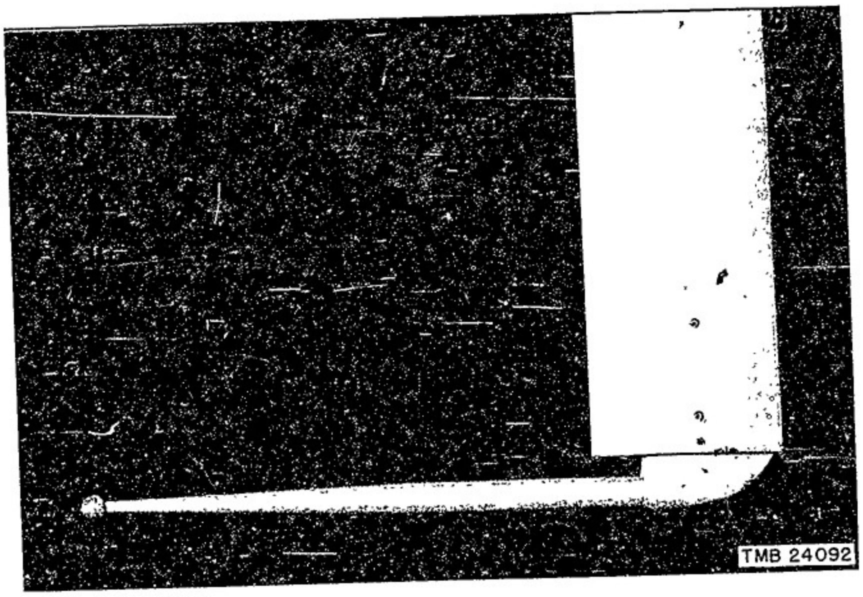


Figure 12a - Lower End of Pitot Tube Strut

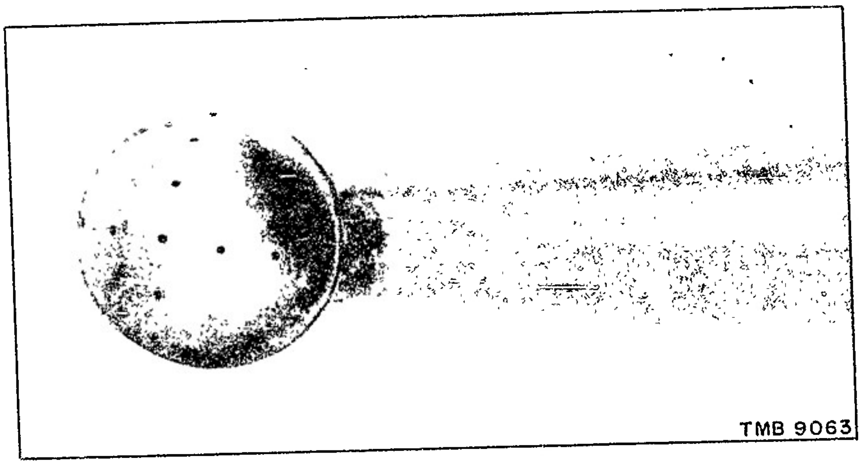


Figure 12b - Closeup of Spherical Pitot Tube Showing Horizontal and Vertical Rows of Holes

Figure 12 - The 13-Hole Spherical Pitot Tube

Details of the construction are shown in Figure 13.

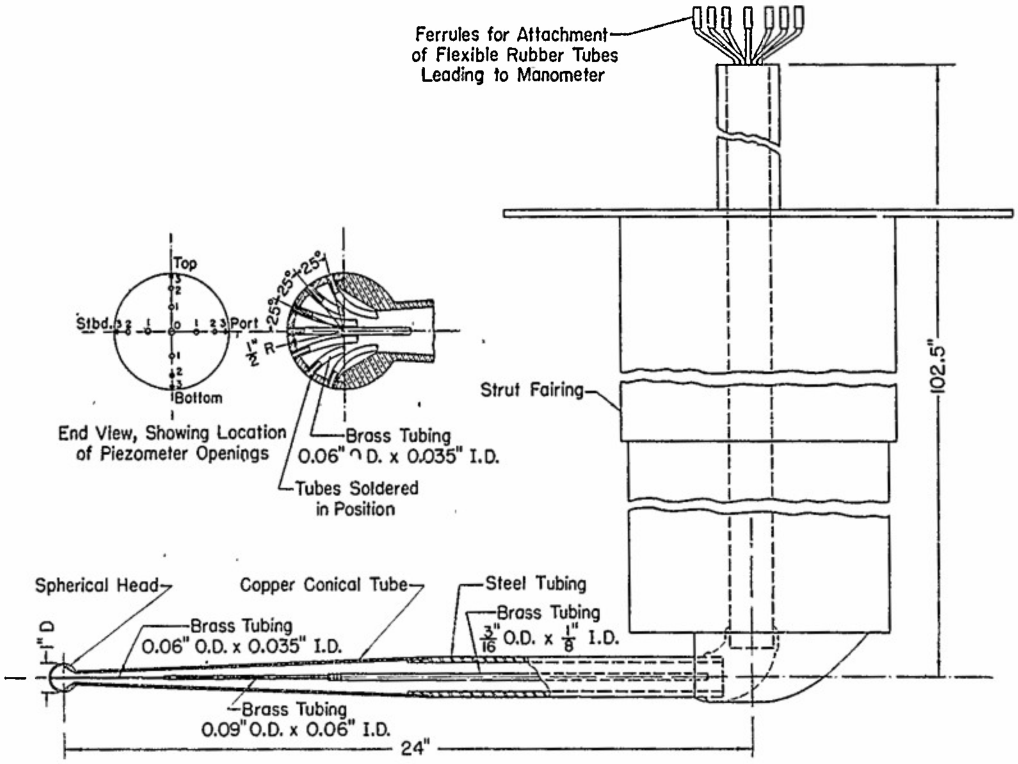


Figure 13 - Construction Details of the 13-Hole Spherical Pitot Tube

The 13-hole spherical pitot tube consists of a 1-inch diameter sphere mounted on the end of an arm extending at right angles from the bottom of a faired strut. The shell of the sphere has 13 piezometer openings, 1/32 inch in diameter, on the forward hemiephere. The holes are drilled along a vertical and a horizontal great circle. One hole is drilled at the extremity of the arm axis known as the pole, and the others are arranged symmetrically about it, 3 on each side, spaced 25 degrees apart. The piezometer openings are connected to a 13-tube manometer by copper tubes through the strut.

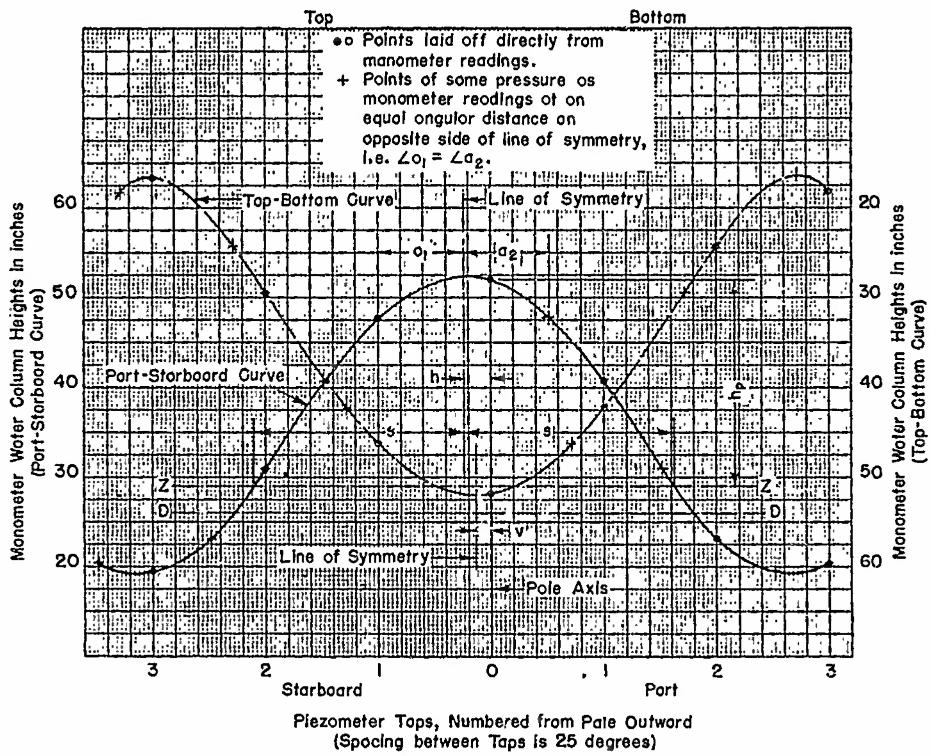


Figure 14 - Typical Curves of the Pressures Measured with the 13-Hole Spherical Pitot Tube

The water level in all the tubes of the manometer before beginning a run is shown by the line D-D drawn only for the port-starboard curve. The steady water level in each tube was plotted as a circle at its corresponding piezometer tap. A smooth symmetrical curve was faired through these spots. The angular distance of the line of symmetry from the pole is shown as h for the horizontal row of holes and v for the vertical row of holes. These two angles are used to determine the direction of transverse flow and the angular distance θ of the stagnation point from the pole by the formula, $\theta = \text{arc tan } \sqrt{(\tan h)^2 + (\tan v)^2}$. The line Z-Z is the value of the local static pressure of the flow about the sphere and is determined by the intersection of the spread angle s with the curve. The spread angle for either curve is obtained from a calibration curve, Figure 16, using the angular distance v of top-bottom curve to determine the spread angle for the port-starboard curve and vice versa.

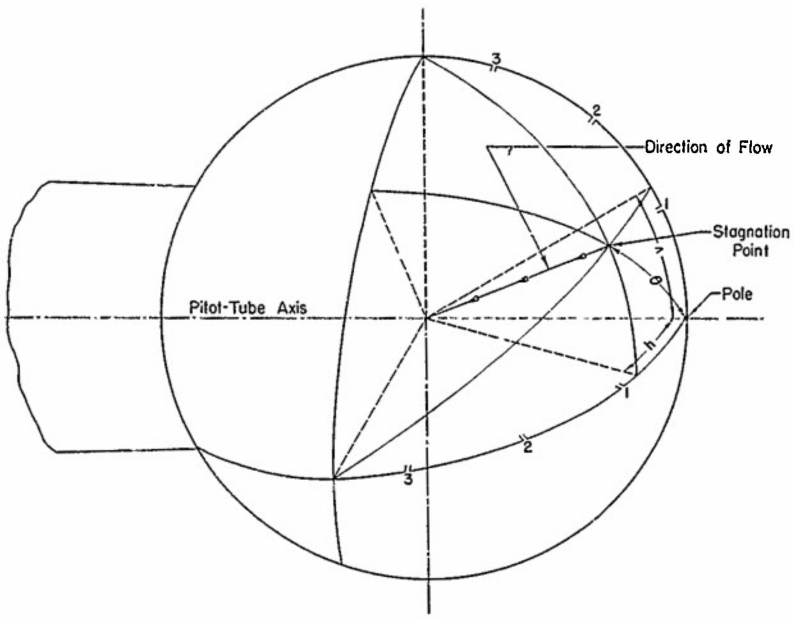


Figure 15 - Sketch Showing the Graphical Determination of the Stagnation Point from the Positions of Maximum Pressure on the Vertical and Horizontal Meridians

When the position of maximum pressure on any meridian is known, the point of maximum pressure on the sphere will be on the great circle drawn perpendicular to, and through the position of maximum pressure on, the meridian. The stagnation point is therefore at the intersection of the two great circles passed through the points of maximum pressure on the meridians of the horizontal and vertical rows of holes. The angular positions of maximum pressure, angles v and h, are obtained from curves (see Figure 14). It is evident that the angle θ is equal to arc tan $\sqrt{(\tan h)^2 + (\tan v)^2}$. The pressure at the stagnation point can be found by dividing the pressure at the pole by a correction coefficient obtained from a calibration of the tube, Figure 16.

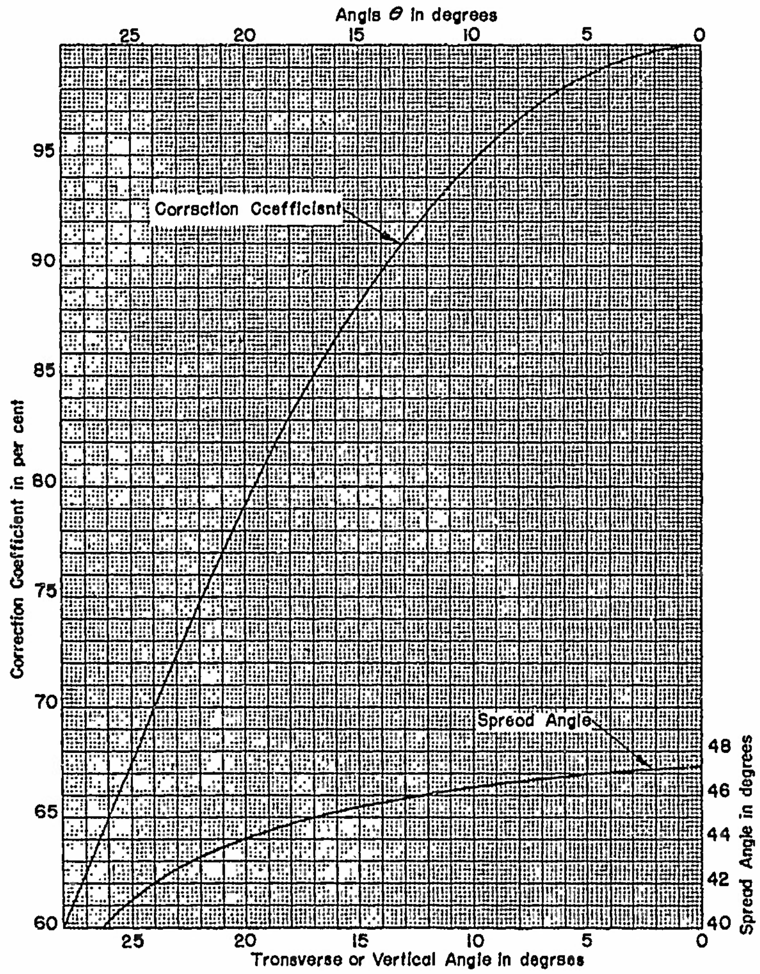


Figure 16 - Calibration Curves for the 13-Hole Spherical Pitot Tube

The correction coefficient is the ratio of the pressure at the pole to the pressure at the stagnation point on the sphere. The angle θ is measured at the center of the sphere in the plane of a great circle through the pole and the stagnation point. The spread angle is the angular distance, on the vertical or horizontal rows of holes, from the point of maximum pressure in the planes of the holes to the point at which the dynamic pressure is zero.

where V_0 is the velocity of flow at the stagnation point in feet per second,
g is the acceleration of gravity in feet per second per second,
H_p is the velocity head in feet at the pole and is equal to the difference between the reading at the pole and the local static pressure, line Z-Z of Figure 14, at the location of the pitot tube, and
K_θ is the correction coefficient for the angle θ obtained from the calibration curve, Figure 16.

Having obtained the velocity V_0 at the stagnation point, the velocity components are calculated from the relations

$$V_a = V_0 \cos\theta \qquad [5]$$

$$V_T = V_0 \sin\theta \qquad [6]$$

where V_a is the longitudinal velocity in feet per second and V_T is the velocity transverse to the axis in feet per second.

The wake fraction is then calculated by means of Equation [2]. The transverse components, expressed as a percentage of V, are laid off as vectors on the wake diagram, the directions of which are determined by the values of h and v, exemplified in Figure 14.

The local static pressure, which is the sum of the potential pressure plus the hydrostatic pressure, at the position of the pitot tube is usually different with the torpedo underway than when at rest. The value of the local static pressure, line Z-Z in Figure 14, is determined by the intersection of the spread angle s with the curve, the spread angle being obtained from the calibration curve of Figure 16. The difference between the local static-pressure level and the datum pressure level, lines Z-Z and D-D in Figure 14, is the numerical value of the potential pressure at the position of the pitot tube with the torpedo underway.

PRNC-4232-1-15-48-100